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Effectiveness of a solar pasteurising device in reducing microbial population of pond water in Bangladesh

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Abstract:

Water plays a vital role in the development of healthy human communities. In Bangladesh groundwater between 70 ft and 300 ft is contaminated with arsenic in many areas while surface water is free of arsenic, but contaminated with enteropathogenic microorganisms, including those of diarrhea, cholera, typhoid, paratyphoid, hepatitis-A, etc. Disinfecting water of harmful microorganisms is relatively easy and can be done in each home, or even in the rural areas. The Biomedical Physics Department of Dhaka University has developed a low cost solar pasteurizer for such applications, which can heat about 5L of water to more than 65^0C in about two hours of clear sunshine. The water in this device is also exposed to UV contributing to a synergy of heat and UV. This study was designed to see the effectiveness and feasibility of this device in reducing microbial population of pond water for drinking purposes. Pond water samples from three different ponds in Dhaka city area were subjected to treatment using this device and the highest temperature achieved was 69^0C after about 2 hours of exposure to sunshine. Regardless of sampling pond, highest bacterial population reduction of 3.9±0.45 log CFU/ml was recorded in non-selective medium.

Keywords: Solar pasteurization device, temperature, pond water, Microbial population

1. Introduction

Drinking water is the most important source of gastro enteric diseases. It is estimated that 884 million people lack access to improved water supplies. Many more forced to rely on supplies having unsafe microorganisms, resulting in a higher risk of waterborne diseases including of typhoid, hepatitis, polio, and cholera. Due to poor sanitation and lack of clean drinking water, there are around 4 billion cases of diarrhea each year resulting in 2.2 million deaths, most of these are children under five [1].

Conventional technologies used for disinfection of non-potable water include ozonation, chlorination, and artificial UV radiation. These technologies require capital intensive, sophisticated equipment, and demand skilled operators [5]

Like other developing countries, in Bangladesh, more than 25 million people lack access to an improved water resource and most of them live in the rural areas of Bangladesh [12].

The critical water situation in Bangladesh involves both the groundwater and the surface water. The groundwater is contaminated with arsenic creating health problems that in the end may lead to death [10]. On the other hand, the surface water contains pathogens causing diarrhoeal diseases and being a major cause of child death [9].

Surface water sources of drinking water in

Bangladesh have historically been contaminated by pathogenic microorganisms, which cause a significant burden of disease and mortality. Diarrhoeal disease is the second leading cause of mortality for children under five years old in the world [2]. It is both preventable and treatable, but still diarrhoea kills around 760 000 children under five each year [11]. In developing countries, like Bangladesh, diarrhoea is also a major cause of malnutrition [2].

In the 1970s gastrointestinal diseases was an acute problem; infants and children suffered the most from these grave diseases as the result of pathogenic contamination in pond water, rivers, lakes etc. [11]. Hence, rapid actions were necessary and tube wells began to be installed [7]. The installation of tube wells spread fast and Bangladesh shifted from drinking surface water to drinking groundwater. Unfortunately, the water turned out contaminated with arsenic.

Tube wells have been used in Bangladesh since the 1940s, but only recently has the problem with arsenic-contaminated water come to light [10]. This is due to the increasing installation of tube wells during the past 30 years and the consequential rising number of persons drinking from them. During the 1970s, the United Nations Children's Fund (UNICEF) and the Department of Public Health Engineering installed tube wells around the country to intentionally provide safe drinking water [7]. At this time arsenic in water supplies was not known as a problem and hence standard testing of water did not include arsenic tests.

In 1993 the first case of arsenic contaminated water was detected and further testing was done in the following years, including investigations of the Department of Occupational and Environmental Health of the National Institute of Preventive and Social Medicine. Results from various laboratories were gathered in a country report of World Health Organization (WHO) in 1996. In about half of the measurements, the arsenic concentrations were above 50 µg/l [10]. This did not meet the guidelines from WHO which the recommended maximum level is 10 µg/l. Even worse was that cases with concentrations higher than 50 µg/l were identified in Bangladesh.

According to survey data from 2000 to 2010, it estimated that about 35 of 77 million people in the country have been chronically exposed to arsenic [7]. This has been described as the largest mass poisoning in history [10]. The mechanism of controlling water borne contaminants by sunlight exposure is due to both the effect of UV radiation and heat.

In order to improve the water situation in rural areas of Bangladesh, a research group at Biomedical Physics and Technology Department, University of Dhaka has been developing a low cost domestic method to remove pathogens from surface water by pasteurization of water using free solar energy. Pasteurization, which destroys all diarrhoeal pathogens, is a process in which water is heated to 60 °C and maintained for 30 minutes [3], or heated to 70 °C and maintained for 15 seconds. Some types of bacteria may still survive, but these are usually harmless [8]. The device involves the use of polyethylene sheets or polyethylene bags filled with water and other available materials in the rural area in order to set up a simple device that creates 'Green House Effect'-conditions. This is essentially a flat plate solar water heater, which provides the safe drinking water to user. In this method, the water is also exposed to UV-light being available in the sunshine, which causes destruction of diarrhoeal pathogens at temperatures somewhat lower than that required in normal pasteurization.

This study was designed by understanding the prevailing conditions and urgency of safe water supplies in flood prone rural communities. To assess the feasibility of solar disinfection of small quantities of drinking water that would satisfy the daily needs of individuals or a family, these experiments essentially consist of subjecting natural and/or artificially contaminated water in small, transparent, 1 to 5 liters in volume, exposure with direct sunlight for varying periods.

2. Materials and Methods

2.1. Sample collection

Water samples were collected in 250ml sterile bottles from approximately 4-5 cm below the pond water surface. This was usually done in between 08h00 to 09h00 hours of the day and transported to the laboratory in an insulated box immediately. In each case, the water was initially examined for bacteriological content just before sunlight exposure. The standard plate count of selective and nonselective microbiological medium was used for the estimation of total bacterial counts, total coliform counts and E. coli counts. Identical batches of water in similar containers were kept at the room in which the light is controlled to compare and assess the effect of sunlight.

2.2. The Experimental Work

Collected water was filtered through eight fold cotton clothes typically known as "sharee" in South Asia. The filtered water was then poured in transparent polyethylene bags (120cm x 120cm). Water was poured up to one third of the polyethylene bags and ensured that the depth of water is within 2.0 cm when the polyethylene bags was laid down on the blackened bamboo tray with the open end placed over the raised edge of the tray. The air bubbles were removed by lightly pushing with fingers. The 9-storied roof of the Center for Advanced Research in Sciences buildings of the University of Dhaka served as the site for these experiments. The hay was spread to a thickness of at least 10 cm on the roof and the bamboo tray with water containing bags was placed on it. Then another transparent polythene sheet was spread over the water bags and few strands of rice straw was spread over the second polyethylene sheet to create an air layer to prevent escaping heat. Then the third polyethylene sheet was spread over the straw and then weight was put in the edges of the polyethylene sheet to prevent wind blowing the polyethylene sheet up. The above-mentioned procedure was named as "Gadget" for water disinfection and shown in Figure 1.

2.3. Preparation of Inoculum

Strains of E. coli isolated from surface water were used in this study. The test strains were adapted to grow in Tryptic Soy Broth (Sigma Chemical Co Ltd, St Lewis, UK) (PH 7.3) supplemented with rifampicin (TSB-Rif ; 50µg/ml). Cultures were transferred to TSB-Rif by loop at three successive 24-hr intervals before they were used as inoculant. Then cells were collected by centrifugation (3000 rpm, 5 min) and re-suspended in sterile normal saline. The lower inoculums with initial concentration of 103 CFU/ml and higher inoculums with initial concentration of 10^8 CFU/ml were maintained at 25°C ±1°C and applied to the pond water within one hour of preparation. Introduction of drug resistant mutations into test strains previously has been used effectively since the selection of bacteria could successfully recover from water environment (Beuchat et al., 2003). Plating on media containing rifampicin greatly minimized the interference of colony development by naturally occurring microorganisms and thus facilitated the detection of test pathogen on recovery media.

2.4. Sample preparation and exposure to sunlight

One ml of lower initial inoculum (10^3 CFU/ml) and higher initial inoculum 108 CFU/ml was added to 1.5 L of "saree" filtered pond water in transparent polyethylene bags separately and exposed to direct sunlight. In every one-hour interval bacteriological count was conducted up to 4 hours. The experiments were generally run from 9h00 to 14h00, when the solar intensity reaches its highest levels. Both the inoculated and non-inoculated filtered pond water was exposed to sunlight separately.

2.5. Microbiological Analysis

During the exposure to sunlight, in every one hour, one plastic bag was picked and decimal diluted (10^{-1} to 10^{-6}) with 0.85% saline water. One hundred microliter (100 µl) of the treated samples were surface plated onto both selective and non-selective medium for non-inoculated pond water.

On the other hand, for inoculated pond water, non-selective Tryptic Soy Agar and selective Coliform Agar were used for total aerobic bacterial count and coliform counts respectively and Sorbitol MacConkey Agar medium supplemented with 50µg/ml rifampicin was used to recover the inoculated bacteria. In addition, Chromogenic Chromocult Agar (MERCK Germany) supplemented with ceftazadime, and pentahydrate were also used as selective medium for the confirmation of *E. coli.* The entire supplement including rifampicin was added to the molten agar before pouring the medium into petri plates. For that reason, only rifampicin resistant bacteria were grown in that medium. All the plates were then incubated at 37°C for 16 to 24 hours before presumptive colonies were counted. All the experiment was repeated three times to confirm the reproducibility.

2.6. Statistical Analysis

All experiments were repeated four times, and duplicate samples were analyzed at each sampling time. Significant differences in plate count data were evaluated using the least significant difference test at the 5% level of significance.

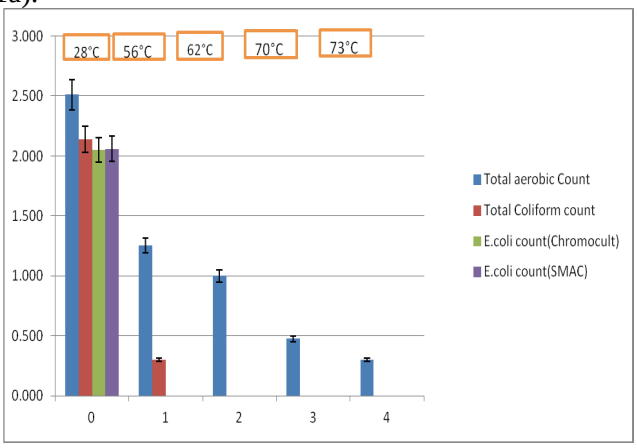
3. Results and Discussion

3.1. Effect of sunlight on different pond water

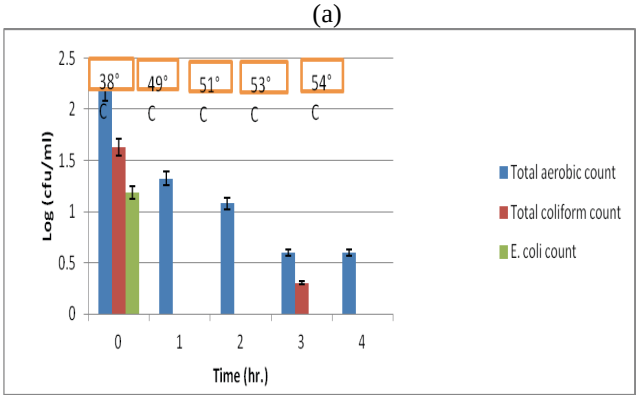
In case of Shahidullah Hall pond water, the initial aerobic bacterial load was recorded as 2.6 log CFU/ml, and coliform count and E. coli counts was recorded as 2.2 and 2.0 log CFU/ml, respectively after saree filtered water (Fig 1a). The physical properties of the treatment day was recorded and observed as clear sunny day, high humidity and sunlight intensity was recorded as 1410 LUX/mn. The initial day temperature was recorded as 28°C at 9h00 and temperature reached to maximum 73˚C at the treatment point of pond water at 14h00. As the temperature increased, the initial aerobic population declined to 1.2 logs CFU/ml after 1h of exposure and decreased further in 2h and 3h and

finally reached to 0.2 log CFU/ml at 4h of sunlight exposure in the gasket.

Total coliform and *E.coli* population decreased significantly after 1 hour of exposure and no survivors were recorded after 2 h of exposure and thereafter (Fig 1a).



(a)



(b)

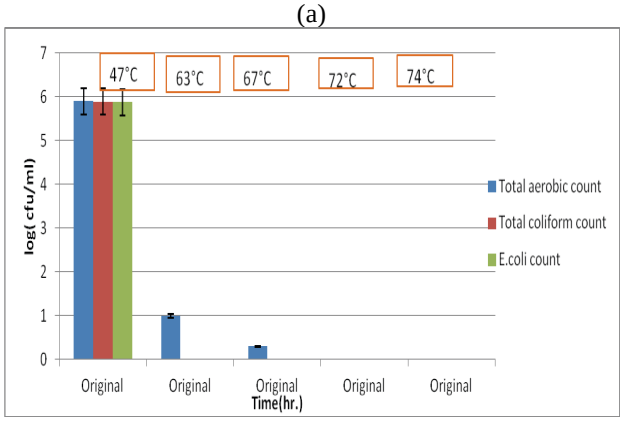
Fig 1 *(a,b) Effect of sunlight on total aerobic, total coliform and E. coli count of Shahidullah Hall pond water. Because of temperature and solar radiation difference of the experiment day, so, different curves (a,b) have been done.*

On the other hand, same pond water were used in treatment on another day (Fig 1b) The physical properties of the treatment day was recorded and observed as cloudy day, with higher humidity and sunlight intensity was recorded as 880 LUX/mn. The initial temperature was recorded as 38^{o}C at the point of treatment at 9h00 and temperature reached to maximum 54˚C at 14h00. The initial aerobic bacterial load was recorded as 2.4 CFU/ml and as the temperature increased, the initial aerobic population declined to 1.4log CFU/ml after 1h of exposure and decreased further in 2h and 3h and finally reached to 0.5 log CFU/ml at 4h of sunlight exposure in the gasket (Fig 1b).

Total coliform and *E.coli* population decreased significantly and after 1 hour of exposure no survivors were recorded. However, there was an increase of total coliform after 3 hours of exposure for unknown reason and no survivor was found at 4 hours of exposure (fig 1b)

In case of artificially inoculated *E. coli* in Shahidullah Hall pond, the initial aerobic bacterial load was recorded as 5.897 log CFU/ml, and coliform count and *E. coli* counts was recorded as 5.892 and 5.875 log CFU/ml, respectively after saree filtered water (Fig 2). The physical properties of the treatment day were recorded and observed as clear sunny day; high humidity and sunlight intensity was recorded as 1660 LUX/mn. The initial day temperature was recorded as 47°C at 10.30 hr and temperature reached to maximum 74°C at the treatment point of pond water at 14.30 hr. As the temperature increased, the initial aerobic population decline to 1 log CFU/ml after 1h of exposure and decreased further in 2h and 3h and finally reached to lower than detection limit.

(a)



(b)

Fig 2. *Effect of pasteurizing device on total aerobic, total coliform and E. coli count of Rifampicin resistant Bacteria (marker Bacteria) of Shahidullah Hall pond water. As because this is not temperature resistant bacteria rather than antibiotic resistant bacteria. So solar radiation has an effect to destroy it.*

In the case of Dhanmondi Lake water, the initial aerobic bacterial load was recorded as 4.84 log CFU/ml, and coliform count and *E. coli* counts were recorded as 3.32 and 3.1 log CFU/ml, respectively

after saree filtered water (Fig 3). The physical properties of the treatment day was recorded and observed as clear sunny day, high humidity and sunlight intensity was recorded as 1645LUX/mn. The initial day temperature was recorded as 33°C at 9.40 hrs. and temperature reached to maximum 74°C at the treatment point of pond water at 13.40 hrs. As the temperature increased, the initial aerobic population declined to 2.54 logs CFU/ml after 1h of exposure and decreased further in 2h and 3h and finally reached to 1.9 logs CFU/ml at 4h of sunlight exposure in the gasket.

Total coliform and *E.coli* population decreased significantly after 1 hour of exposure and no survivors were recorded after 2 h of exposure and thereafter (Fig 3).

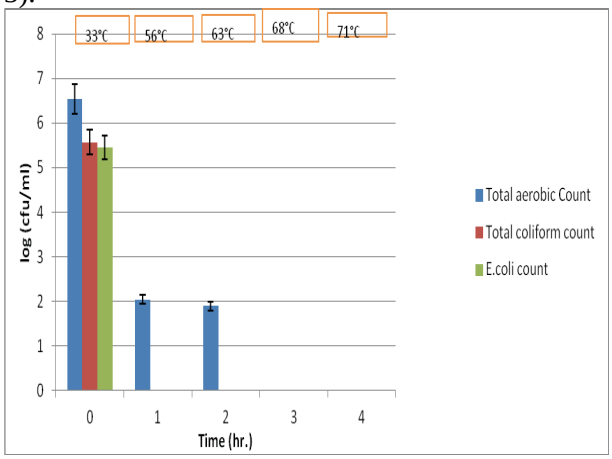


Fig 3. *Effect of sunlight on total aerobic, total coliform and E. coli count of Dhanmondi lake water*

In the case of artificially inoculated *E. coli* in Dhanmondi Lake, The initial aerobic bacterial load was recorded as 6.54 log CFU/ml, and coliform count and E. coli counts were recorded as 5.56 and 5.44 log CFU/ml, respectively after saree filtered water (Fig 4). The physical properties of the treatment day was recorded and observed as clear sunny day, high humidity and sunlight intensity was recorded as 1870 LUX/mn. The initial day temperature was recorded as 33°C at 10.40 hr and temperature reached to maximum 71°C at the treatment point of pond water at 14.40 hrs. As the temperature increased, the initial aerobic population declined to 1 log CFU/ml after 1h of exposure; decreased further in 2h - 3h; and finally reached to below the detection limit (Fig 4)

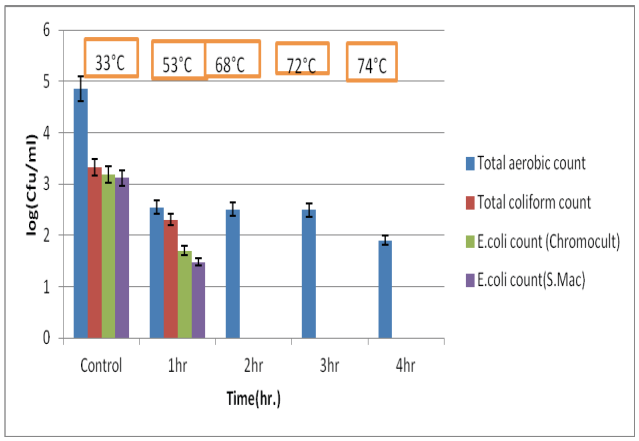
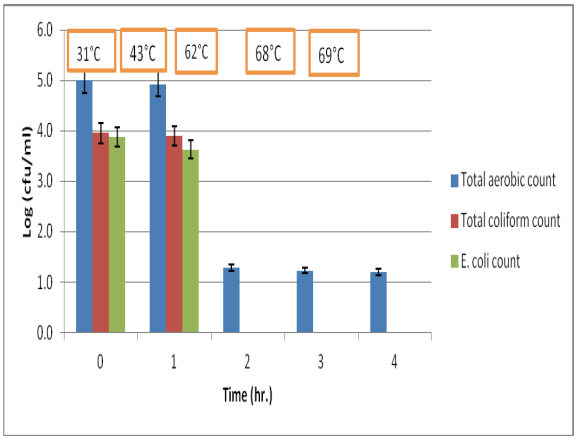


Fig 4. *Effect of pasteurizing device on total aerobic, total coliform and E. coli count of Rifampicin resistant Bacteria (marker Bacteria) of Dhanmondi lake water. As because this is not temperature resistant bacteria rather than antibiotic resistant bacteria. So solar radiation has an effect to destroy it.*

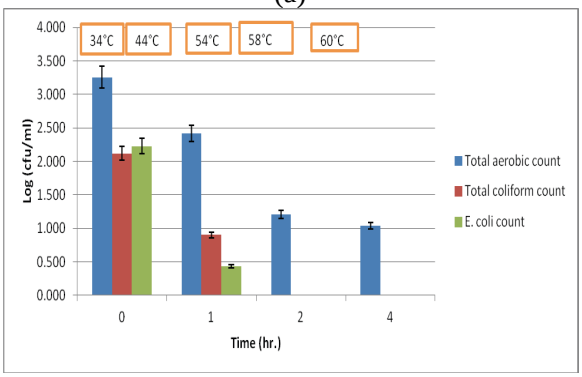
In the case of Bangla Academy pond water, the initial aerobic bacterial load was recorded as 5.0 log CFU/ml, and the coliform count and E. coli counts were recorded as 4.0 and 4.0 log CFU/ml, respectively after saree filtered water (Fig. 5). The physical properties of the treatment day was recorded and observed as clear sunny day, high humidity and sunlight intensity was recorded as 1610 LUX/mn. The initial day temperature was recorded as 31°C at 9h00 and temperature reached to maximum 69°C at the treatment point of pond water at 13h00. As the temperature increased, the initial aerobic population declined to 1.1 log CFU/ml after 2h of exposure and thereafter no decrease in 3 and 4 h of exposure in the gasket.

Total coliform and *E.coli* population decreased significantly after 2 hour of exposure and no survivors were recorded after 2 h of exposure and thereafter (Fig 5a).

On the other hand, same pond water in another treatment day was conducted. The physical properties of the treatment day was recorded and observed as cloudy day, with higher humidity and sunlight intensity was recorded as 1620 LUX/mn. The initial temperature was recorded as 34°C at the point of treatment at 10h00 and temperature reached to maximum 60^0C at 14h00. The initial aerobic bacterial load was recorded as 3.25 log CFU/ml and as the temperature increased, the initial aerobic population decline to 1.2log CFU/ml after 3h of exposure and little decreased further at 4h of sunlight exposure in the gasket (Fig 5b).



(a)



(b)

Fig 5 (a,b). *Effect of sunlight on total aerobic, total coliform and E. coli count of Bangla Academy pond water. Because of temperature and solar radiation difference of the experiment day, so, different curves (a,b) have been done.*

Total coliform and *E.coli* population decreased significantly after 1 hour of exposure no survivors were recorded after 2 h of exposure and thereafter (Fig 5b).

In case of artificially inoculated *E. coli* in Bangla Academy pond, the initial aerobic bacterial load was recorded as 5.596 log CFU/ml, and coliform count and E. coli counts was recorded as 5.35 and 5.34 log CFU/ml, respectively after saree filtered water (Fig. 5). The physical properties of the treatment day was recorded and observed as clear sunny day, high humidity and sunlight intensity was recorded as 1730 LUX/mn. The initial day temperature was recorded as 32°C at 11.10 hr and temperature reached to maximum 69°C at the treatment point of pond water at 15.10 hr. As the temperature increased, the initial aerobic population decline to 2.11 log CFU/ml after 1h of exposure and decreased further in 2h and 3h and finally reached to 0.3log CFU/ml. (Fig 5)

Total coliform and *E.coli* population decreased significantly after 1 hour of exposure no survivors were recorded after 2 h of exposure and thereafter (Fig 5).

Conclusion

In this study, effectiveness of solar pasteurizing device on reducing microbial population has to be determined. Two of the most significant factors are the solar radiation and time to have a safe water quality. Since insulation and air gap thickness, as well as time duration in the sun, have a major impact on temperature, these have been the main focus during the study. Solar radiation is the general source of heat, and necessary to achieve an adequate water treatment, but if the insulation of the device is lacking, the heat loss would be considerable and the rate of temperature increase will be reduced significantly. Double thickness of insulation showed capacity of retaining the solar energy longer and thus water temperature would be higher.

One of the greatest difficulties while performing the solar radiation test was the maintenance of the same initial temperature among all tests, since the outdoor temperature was not as constant as the indoor temperature. The preparation time in the sun before starting the tests varied slightly each time, and also affected the starting temperature of the water. Besides the variation in time for preparation, other impacts such as the initial temperature of the table, where the device was placed during the test, also fluctuated due to the solar radiation. These issues could explain why the results are different.

The microbiology studies show that the low cost solar pasteurization device can purify pond water to supply safe drinking water. To extend the study further, more microbiology samples should be taken from rivers and other ponds in rural areas. The pond near the institute is not entirely representative of the rural areas and the day when the test was made the sun had pre-heated the water in the pond. This might have affected the water quality and reduced pathogens already before treatment with the pasteurizing device. This could be the reason for the low value of pathogens in the reference samples.

In a clear sunshine typical day in Bangladesh (during February to July), when the solar radiation is the strongest, the device could be able to disinfect three water volumes per day. This will give 4 liter of water in late spring and during summer. In the winter (December to February) when the solar radiation is less strong to water volumes per day will be possible to obtain, which provides 3 liter soft water.

The costs per liter water using the solar water pasteurizer would be around 400 taka, which is around US Dollar 5. Which is very low cost to achieve. Otherwise, this device is made of such things (Black color bamboo tray, straw, polyethylene sheets, Polyethylene), which is available in the rural areas, if people aware before flood and arrange these materials, then they can use this device to during flood.

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